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Research Article

Effects of the total solar eclipse of March 9, 2016 on the animal behaviour

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Abstract
Studies on animal behaviour associated with natural phenomenon such as a solar eclipse, provides valuable contribution to the ecology of the studied animal. An observation on the effect of the total solar eclipse on the environment and animal behaviour was done in Central Sulawesi, Indonesia on March 8-9, 2016. Four recorded environmental factors changed dramatically during the solar eclipse. Air temperature, light intensity, and wind-speed dropped and reached the peak around the maximum eclipse, whereas humidity increased at the same time. The observed animals, i.e. Heck's macaque, flying fox, maleo, amphibians, and several insects showed unusual behaviour as a response to the environmental changes. Meanwhile, tarsier showed no response to the solar eclipse. This observation revealed the effect of the total solar eclipse on the environment and animal behaviour.

Keywords: behaviour, eclipse, response, Sulawesi

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Introduction

A total solar eclipse is a rare natural phenomenon with only 68 occurrences during the 21st century, and has an effect on animals, plants and environmental factors (Pasachoff, 2009). Previous studies report the dramatic reduction of incoming global radiation, pronounced changes in surface temperature and humidity and also decrease in wind-speed associated with the eclipse event (Anderson et al., 1972; Founda et al., 2007). Environmental factor changes, especially decreasing light intensity and temperature effect animal behaviour.

The unusual behaviour of animals during the solar eclipse have been recorded in previous studies. The earliest records were of birds ceasing to sing and falling to the ground during total eclipses in 1544 and 1560 respectively. Thereafter, Newport (1837) reported bees returned to their hives during an eclipse. The scattered observations on mammals, some insects and plants have been done by astronomers who were primarily occupied with observing the eclipse, only when they had the good fortune to be a situation to observe the animals (Wheeler et al., 1935). Comprehensive records were presented by Wheeler at al. in 1935 by compiling reports from society during the total solar eclipse in New England states on August 31, 1932. After some decades, more scientists realized and gained information from their observations on animal behaviours. Beginning in 1955, Kullenberg reported bird and insect behaviour during the solar eclipse, and this was followed by other reports such as on bats (Krzanowski, 1959), freshwater invertebrates (Cadwallader & Eden 1977), chimpanzee in captivity (Branch & Gust 1986), and spiders (Uets et al., 1994). During the 2000s there were reports on birds by Tramer and ground squirrel by Kavanue and Rischer, in 2000 and 2009 respectively.

Although there are a number of reports, this phenomenon is always unique since it happens at different times of day, locations and conditions (Founda et al., 2007). On March 9, 2016, a total solar eclipse passed over the Indonesian archipelago. Almost the whole Indonesian territory was covered by the eclipse, with 65% of the minimum eclipse totality at the furthest area from the total eclipse's path. Thus, in order to study the effect of the total solar eclipse of March 9, 2016, we conducted observations and a field experimental study. This paper presents our result on recorded animal behaviour and environmental factors before and during the total solar eclipse.

Materials and Methods

Observations were conducted in Central Sulawesi i.e. Lore Lindu National Park (LLNP), Pangi-Binangga Nature Reserve (PBNR) and Pulau Kelelawar (**Figure 1**). LLNP and PBNR were located in the central axis of the eclipse with 100% sun obscuration, while Pulau Kelelawar was about 60 km away with 99% of sun obscuration.

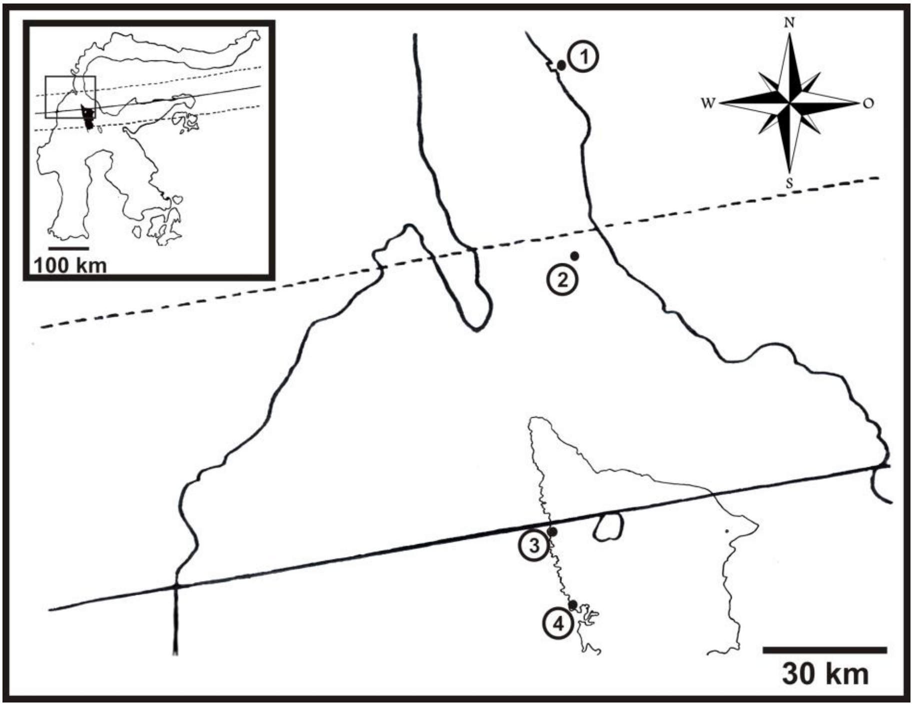

Figure 1. Observation sites: 1, Kelelawar Island; 2, Pangi-Binangga Nature Reserve; 3, Saluki (Lore Lindu National Park); and 4, Mata'uwe (Lore Lindu National Park). Black line is the center of the total solar eclipse, while the dotted line is the border of the total solar eclipse path with 100% obscuration.

The duration of the eclipse was 2 hours 32 minutes (details in Table 1 and Figure 2). The first partial eclipse started at 07.27 hours (T1, the first contact between the moon and the sun) until 08.37 hours (T2, the shadow of the moon fully covered the sun), while the second partial eclipse began at 08.40 hours (T3, the end of the total eclipse) until the end of the eclipse at 10.00 hours (T4, the sun was fully visible). The solar eclipse started when the height degree of the sun was 15-30°, which means that the eclipse started when the sky was already bright.

Table 1. Total Solar Eclipse on March 9, 2016: Time and sun position Lore Lindu National Park (Lat.: 1.4364°S Long.:120.1317°E) (generated and modified from https://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2016Mar09Tgoogle.html)

Event	UTC	Central Indonesian Time (WITA)	Altitude	Azimuthal
Start of partial eclipse (T1)	23:27:40.1	07:27:40.1	19.5°	094.2°
Start of total eclipse (T2)	00:37:21.9	08:37:21.9	36.8°	094.4°
Maximum eclipse (M)	00:38:43.8	08:38:43.8	37.2°	094.4°
End of total eclipse (T3)	00:40:06.4	08:40:06.4	37.5°	094.4°
End of partial eclipse (T4)	02:00:33.6	10:00:33.6	57.6°	095.9°

Therefore, these study sites were the best places for carrying out animal observation. In addition to the high animal diversity and endemism in Sulawesi, the duration of the total eclipse in these sites was longer. Moreover, there was a gap between dawn (sunrise) to the beginning of the eclipse.

The instantaneous scan-sampling technique was applied by observing one or a group of animals, recording what these animals did at predetermined time intervals, beginning one day before the eclipse and continuing through the day during the eclipse (Altmann, 1974; Branch & Gust, 1986). Several groups of animals which represent nocturnal and diurnal animals were observed in their natural habitats, i.e. Black flying fox (*Pteropus alecto*) in Pulau Kelelawar, Heck's macaque (*Macaca hecki*) in PBNR, Tarsier (*Tarsius dentatus*) in Mataue-LLNP, four species of amphibians: Sulawesian toad (*Ingerophrynus celebensis*), Common Asian toad (*Duttaphrynus melanostictus*), Crab eater frog (*Fejervarya cancrivora*), Chorus frog (*Microhyla* sp.) in paddy fields around Saluki, and also insects in Saluki-LLNP. Maleo (*Macrocephalon maleo*) was observed in the semi-natural captivity Saluki-LLNP. A group of maleo comprising adult males, adult females and chicks were kept in a cage which was built in their natural habitat at LLNP. Behaviour of the other animals were also recorded opportunistically.

Camera recording and direct observations were conducted to record the behaviour of birds and mammals. Camera traps (Bushnell NatureView HD) equipped with night vision devices were set up in the roosting site of the flying fox, nest tree of the tarsier, and the semi-natural captivity area of maleo. All the animals were observed directly. In the visual observation of the amphibian, an advertisement call recording was also be done using asound recorder (Olympus LS 11 with built-in microphone). The call recording provides information on the activity and identity of the observed species. An experimental field study was conducted to observe the behaviour of ball-rolling dung beetles (*Paragymnopleurus planus*) (Dacke et al., 2014). A circular dirt arena (3 metres in diameter) was prepared, and then one dung ball and a beetle were placed in the centre of the arena, letting the beetles roll the ball out of the circular line. Behaviour of the dung beetles were observed in two replications starting 30 minutes before the beginning of the eclipse until 30 minutes after the end of the eclipse. A light trapping was conducted to observe the response of diurnal-nocturnal insects, such as Coleoptera, Lepidoptera, Orthoptera, and Hemiptera. Light trap was constructed using two mercury lamps (*Phillips ML L* 160W 220V each) with electricity source provided from 1.000W *Honda EU 10i* portable generator. Lamps were mounted in the square white cloth, 3 x 2 metres in dimension. Light trappings were done from 07.00 to 10.00 hours at the Indonesian Central Time (WITA) the day before eclipse (March 8) and during the day when the eclipse happened. Additionally, four environmental factors were recorded from 06.00 to 11.00 hours beginning a day before the eclipse and ending after the eclipse. Air temperature, humidity, and wind speed were measured using a Kestrel 3000 pocket wind meter, while the light intensity was recorded by using the lux-meter.

Results and Discussion

Recorded environmental factors

All the measured environmental factors changed dramatically during the eclipse (**Figure 3**).

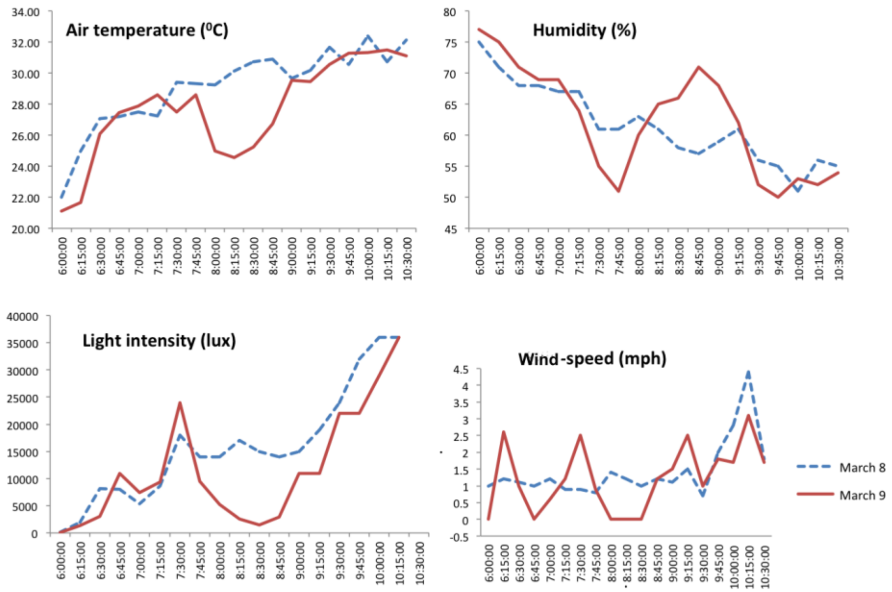

Figure 3. Recorded environmental factors. A day before eclipse, March 8 (dotted-blue line) and during the solar eclipse, March 9 (red line).

Air temperature, light intensity, and wind speed dropped and reached their peak around the time of the maximum eclipse, whereas humidity increased through the eclipse. The air temperature decreased significantly in all sites, from 28.61°C to 24.56°C, starting about 20 minutes after the first contact (T1), as a response to the sun radiation blocking (Anderson, 1999; Szalowski, 2002). Relative humidity increased for several minutes after T1, from 51% to 71%, as a consequence of the decreasing temperature (Founda et al., 2006). The light intensity dropped completely at T1, from 25.000 lux to near 0 lux during the maximum eclipse. Wind speed fluctuated during the day, however, it decreased at T1 and was stable around the maximum eclipse. Significant environment changes during the solar eclipse were expected to affect animal behaviour. Animals showed unusual behaviour, differing from their behaviour in normal conditions.

Animal responses

Black Flying Fox (*Pteropus alecto*) showed different behaviour during the solar eclipse. A day before the solar eclipse, almost all individuals produced a calling-sound and were noisy in their roost, from around 07.00 hours until noon. At 08.00 hours, some individuals flew around the tree-roosts, interacted with other individuals and flapped their wings more often. On March 9, they showed a similar behaviour in the morning but from 08.15 hours, the roost was very quiet, all individuals hung stably, and covered their bodies with wings **(Figure 4)**. This situation continued until 09.15 hours, about half of the second partial eclipse. At 09.30 hours some individuals flew around the tree-roosts, similar to the day before. It was predicted this unusual behaviour was a response to the environmental factor changes which suddenly happened during the total solar eclipse, especially the decrease in temperature and darkness (Wheeler et al., 1935). Additionally, flying fox did not emerge from their roost during the eclipse. It was argued that bats fly out from the roost during the eclipse because of the darker sky, creating a similar situation as evening when they emerge daily (Krzanowski, 1959).

Dian's Tarsier (*Tarsius dentatus*) showed no response to the solar eclipse. In daily normal conditions, this species produces an audible calling-sound which can be heard directly, and comes out from the nest to forage for prey in the evening (Řeháková-Petrů et al., 2012). Our observation and camera recording analysis show that the tarsier stayed inside the nest and did not produce a calling during the solar eclipse **(Figure 4)**. Although the tarsier is a nocturnal animal, we predicted that there is no effect on the tarsier's activity due to darkness caused by the eclipse.

Figure 4. Several observed animals. Black flying fox hang stably in their tree-roost (a), Tarsier stay inside the nest (b), Maleo in their semi-natural captivity (c), Amphibian (*Michrohyla* sp.) produce advertisement call during the eclipse (d), Dung beetles roll the dung ball (e), and moths in the light trap (f).

Heck's macaque (*Macaca hecki*) is one of the diurnal primates that was observed intensively. On March 8, they moved down from the resting tree and spent their time foraging, feeding, moving, and socializing from 05.43 to 10.30 hours, then took a rest on the canopy. At 11.23 to 17.36 hours they went deep into a forest with steep topography and could not be observed. However, they came back to their resting tree before the sky went dark as this is their usual daily activity (Reichard, 1998). On March 9, they showed similar activities in the morning. However, at 08.34 hours, they ceased all activities. Three males emitted a loud sound like '*wa-wa-wa*', as a command for other individuals to gather around the alpha male. The sound is supposed to be a call or a sign of a dangerous situation. Afterward, the alpha male moved down to the ground, followed by juveniles, females and some males and formed a circle with an alpha male at the centre. Thierry (1983) also reported the same pattern of emitted sound and circle formation of the Tonkean macaque (*M. tonkeana*) in LLNP when they were under threat or attack. When the total eclipse began, they did not move from their initial position, except for the alpha male and one other sub-adult male. After the end of the total eclipse, the adult male made some noises and interacted with the other individuals, then moved deep into the forest, and came back to the resting tree in the afternoon. A similar unusual behaviour of other primates during the solar eclipse has also been recorded by Branch & Gust (1986). According to their observation, the rare and uncommon events such as solar eclipse can influence and modulate the behaviour of chimpanzees.

Domesticated pig (*Sus* sp.) was observed opportunistically. Several minutes after the partial eclipse began (T1), they ceased their activities including eating, and took a rest position. These activities are appropriate to the dusk condition, which has been recorded in other mammals, such as squirrels (Wheeler et al., 1935). The normal activities began afterwards when the sky became brighter, before the end of the partial eclipse (T4).

The behaviour of the maleo (*Macrocephalon maleo*) has been observed visually and recorded using night vision camera in the semi-natural captivity. A day before the solar eclipse, all individuals showed normal activities such as feeding on the ground, moving around, and interacting among individuals. On March 9, from 08.00 hours (T1), unusual activities were recorded. Maleo showed anxious behaviour which was expressed by irregular movement in the cage. The male flew to the artificial nest, which was formed using a tree branch in a higher position inside the cage, and behaved like it was taking a rests prior to nightfall. This unusual behaviour is rarely seen during a normal day. Female maleo ceased the activities and stayed on the ground. Around 09.15 hours (T3), the female showed normal activity, while the male flew down to the ground and interacted normally with the females and chicks.

The other avian fauna, a colony of birds, foraged in the tree (*Ficus* sp.) and produced noisy calling in the morning until noon on March 8. However, on March

9, these birds foraged only in the morning until the first partial solar eclipse (T1). Close to the total solar eclipse, all of them flew away, probably back to their nests. Our observation showed a similar pattern with previous studies (i.e. Maccarone, 1997; Tramer, 2000), and agreed that although the solar eclipse was short, reduced light levels sufficiently interrupted normal avian diurnal behaviour patterns.

Four nocturnal species of amphibians were observed in the paddy field. The night before the eclipse, all of the observed species produced an advertisement call. On March 9, at the beginning of the first partial eclipse (T1), two species, *F. cancrivora* and *D. melanostictus* were actively feeding while *I. celebensis* and *Microhyla* sp. were inactive and stayed in the hollow embankment. When the sky started to become darker and the air temperature decreased (after T1), *F. cancrivora* changed its position, while *D. melanostictus* jumped to the upper embankment and hid under the grass. At the maximum eclipse, when the air temperature dropped significantly by 4°C, *I. celebensis, D. melanostictus* and *F. cancrivora* kept inactive at the same position, while *Microhyla* sp. produced their advertisement call. We predicted that the significant temperature change affected the activities of these amphibians making them less active. The decrease of the light intensity during the maximum eclipse reflects the situation at night. This situation triggered some amphibian species to produce the advertisement call (Wheeler et al., 1935).

An experimental field study was carried out to know the effect of the total solar eclipse to the roller-type dung beetles, *Paragymnopleurus planus*. The rolling speed was slower during the first and second partial eclipses, compared to normal conditions. Interestingly, during the maximum eclipse, *P. planus* stopped rolling the dung ball and buried itself inside the ground in the cower-sleep position. The dung beetles reappeared to the ground level when the sun began to become brighter and continued rolling the dung ball. According to Dacke et al. (2014), dung beetles utilize celestial compass cues such as the sun, moon, the pattern of polarized light of the sky and the milky-way to navigate a straight line while rolling the dung ball. Therefore, the lack of navigation signals which were caused by the total solar eclipse affected the dung beetles' behaviour. They stopped rolling the dung ball and could not navigate accurately.

Turning to the light trap results, no insects were trapped during 07.00 to 10.30 hours the day before eclipse, as we had expected. However, after the partial eclipse began (T1), two species of diurnal insects from the families Coccinellidae and Chrysomelidae were recorded coming to the trap. Meanwhile, there was no record of nocturnal insects very common to be found in the light trap i.e. Lucanidae, Scarabaeidae, and Cerambycidae. Interestingly one of the nocturnal insects, such as the moth, was recorded coming to the trap during the solar eclipse **(Figure 4).** Additionally, several unusual insect behaviour were also recorded opportunistically, i.e. chirping and shrilling of crickets and cicadas during the eclipse. Crickets became very noisy during the total solar eclipse, louder than usual (Wheeler et al., 1935). Chirping or shrilling of crickets and cicadas is common at night or in the evening when the sky gets darker, however, it is unusual to hear this during the day.

Our study recorded the environmental factor changes associated with the solar eclipse affecting the observed animal behaviour (**Table 2**). Diurnal animals ceased their activities, went back to their nests, or took the rest position, whereas nocturnal animals became active during the solar eclipse. All of these unusual behaviours are assumed as the exogenous rhythm expressions, and they revert to normal behaviour when conditions are stable (Hardy, 1970). A question related to this phenomenon can be addressed for future research, i.e. what kind of adaptation will be expressed if the influenced phenomenon, such as solar eclipse's similar condition situation occurs frequently?

Recorded data and information from this observation can be utilized to conduct future studies on animal behaviour associated with environmental changes. As we know, the environment is changing continuously due to many factors, such as increasing human population and habitat degradation. Therefore, a study on animal behaviour would be important to know their ecology and to develop the appropriate conservation management plan.

Table 2. Activities of the observed animal at normal conditions and during the solar eclipse

Animal	Usual activities	Activities during solar eclipse
Nocturnal animal		
Flying fox (*P. alecto*)	produce call-sound, flap the wing, interact each other, noisy, some individuals fly around the roost	quiet, cover their body with the wing, roost stably, do not emerge from the roost tree.
Dian's Tarsier (*T. dentatus*)	stay inside the nest, do not produce calling during the day	do not response the solar eclipse, stay inside the nest and do not produce calling
Sulawesian Toad (*I. celebensis*)	active and produce advertisement call at night	inactive
Common Asian Toad (*D. melanostictus*)	active and produce advertisement call at night	inactive
Crab-eater frog (*F. cancrivora*)	active and produce advertisement call at night	Inactive
Chorus frog (*Microhyla* sp.)	active and produce advertisement call at night	produce advertisement call
Moth	attracted with light trap during the night	attracted with light trap
Diurnal animal		
Heck's macaque (*M. hecki*)	forage, play/socialize	silent, cease activities, except males which emitting sound at partial eclipse. All individual cease activities at their position at total eclipse
Maleo (*M. maleo*)	feed in the ground, move around, interact each other	a male fly to the resting nest, female cease activities and stay in the ground
Domestic pig (*Sus* sp.)	eat the provided food	cease activities and take a rest position
Ball-rolling dung beetles (*P. planus*)	roll the dung ball normally	roll speed slower at first and second partial eclipse, stop rolling and burry itself inside the ground

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